NUMERICAL AND EXPERIMENTAL ANALYSIS OF WAKE EFFECT ON TIDAL CURRENT TURBINE

MUHAMMAD SHAHRUL BIN SABRI

Report submitted in partial fulfillment of requirements
for the award of Bachelor of Mechanical Engineering

FACULTY OF MECHANICAL ENGINEERING
UNIVERSITY OF MALAYSIA PAHANG

JULY 2013

ABSTRACT

The tidal current energy is one of the renewable energy existed on earth. Malaysia has the potential to develop a technology which can utilize this energy to generate electricity. The installation of marine current turbine array requires a deep research to maximize the potential energy of the sea current. Numerical and experimental investigation of tidal current energy extraction has been conducted in this study. Using commercial computational fluid dynamics (CFD) code ANSYS, the lab scale water flume was simulated. For the numerical model, tidal current turbine are represented by an actuator disk instead of scaled down turbine. The actuator disk produces a pressure drop which can be used to calculate the thrust coefficient. The turbulence kinetic energy and the velocity are closely monitored to investigate the wake effect produce. For experimental investigation, a 1m long, 0.2m high and 0.3m width of water channel fabricated. The same parameter which is velocity and turbulence effect downstream are closely monitored thus comparing the result with numerical simulation. Flowmeter is used to read the velocity of the current in the water channel. The result shown wake recover up to 70% at 4D for every numerical and experimental investigation.

ABSTRAK

Tenaga arus laut adalah salah satu tenaga boleh diperbaharui yang wujud di muka bumi. Malaysia mempunyai potensi untuk membangunkan teknologi yang boleh menggunakan tenaga ini untuk menjana elektrik. Pemasangan susunan turbin marin yang boleh mengekstrak tenaga arus laut memerlukan penyelidikan yang mendalam untuk memaksimumkan penjanaan tenaga arus laut. Penyiasatan berangka dan percubaan pasang surut pengeluaran tenaga semasa telah dijalankan dalam kajian ini. Menggunakan dinamik bendalir pengiraan komersial (CFD) ANSYS kod, makmal skala flum air telah disimulasi. Bagi model berangka, turbin air diwakili oleh cakera penggerak bukannya turbin yang telah dikecilkan. Penggerak cakera hasil kejatuhan tekanan yang boleh digunakan untuk mengira pekali teras. Tenaga kinetik dan pergolakan halaju yang memantau untuk mengkaji kesan ekoran yang dihasilkan. Untuk siasatan ujikaji, salurasn air telah diperbuat dengan ukuran 1m panjang, 0.3m lebar, dan 0.2m tinggi. Parameter sama iaitu halaju dan kesan hiliran pergolakan yang dipantau itu dibandingkan hasilnya dengan simulasi berangka. Flowmeter digunakan untuk membaca halaju semasa dalam saluran air. Hasilnya ditunjukkan arus air kembali semula sehingga 70% pada 4D bagi setiap siasatan berangka dan eksperimen.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

RE	Renewable Energy
MCT	Marine Current Turbine
RTT	Rotach Tidal Turbine
POM	Princeton Ocean Model
EES	Engineering Equation Solver
TPXO	OSU TOPEX/POSEIDON Crossover

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Tidal energy is a form of energy created when the natural rise and fall of ocean surface happen. It is caused by the gravitational field of the sun and the moon. There are two ways the tidal energy can be turned to electricity which is by using tidal barrage and tidal stream approach. Although tidal barrage may develop in Malaysia but it is not economically viable due to high construction cost [1]. There are many countries has been used the tidal energy to generate electricity. France and South Korea are the leader in this hydropower technology. The La Rance and Lake Sinhwa are the respective tidal power station for both countries.

The tidal stream however can be a good source of renewable energy for Malaysia because Malaysia has a few locations with high tidal stream energy [1]. This tidal stream energy can be utilized to become the main energy resource to generate electricity in Malaysia one day. If the tidal energy become the main energy resource of Malaysia it may be able to overcome problems due to the low resource of natural gas and oil.

To achieve this mission, a very deep and thorough research need to be done and more knowledge need to be acquired. There are only very few research has been made lately. This thesis is to increase knowledge of tidal energy in Malaysia.

1.2 PROBLEM STATEMENT

Most of the country nowadays has an awareness of available renewable energy resources. People know that at one time, the energy cannot be generated by non renewable energy resources like coal or natural gas anymore. The world however has a really large of renewable resource. It includes biomass energy, wind energy, solar energy and hydropower energy. This available resources can be utilized to its greatest potential and can be the main energy use which generate the world electricity someday.

Malaysia, the front leader of developing country are going towards the utilization of renewable energy. Tidal is one of renewable energy resource in Malaysia. According to reference [2], Malaysia has thirty nine units of mini hydro with total capacity of 16.185 MW in Peninsular Malaysia, seven units of total capacity of 2.35 MW in Sabah and 5 MW in Sarawak. However the value is still small and further research and development need to be established to enhance this renewable energy.

1.3 RESEARCH OBJECTIVES

Around the world, the marine current energy converter is located in a compact site where the tidal current are constrained such as between the islands, around headlands or estuarine-type inlets [3]. The tidal turbine then needs to be installed in an array so that it is cost efficient. Since the water current possesses a different flow characteristic than the wind, the understanding of the wake effect needs to be researched so that the performance of a tidal turbine array can be kept at its highest. This study aims to understand the effect of wake from tidal turbine within a set of data obtained in a Malaysian sea.

1.4 SCOPE OF THE STUDY

1. Data obtain on tidal current in Malaysia.
2. Actuator disk use as a scale down turbine.
3. Analysis the wake effect using numerical method.
4. Experimental investigation in water channel.
5. Data analysis by comparing numerical and experimental investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The ocean energy are from four different resources which are wind, tidal, thermal or marine currents. This energy can be used as large scale sustainable electrical power[4]. Although the wind energy is more common resources developed [4], it should not be the only one resources to be focused.The tidal current especially has a very large capacity of energy and can be utilised to be use as renewable energy. Tidal currents have its potential for the generation of renewable energy [5].

Globally, tidal energy is estimated at 2.5 TW of potential power [6]. Hydropower is the only renewable energy source that can boast a substantial share of today's electricity generation [7]. On 2007, hydropower energy share amount of 17% corresponding to total energy supply of EU [8]. Futhermore, this energy has no critical impact to the environment [9]. It is known that there are a few problems regarding to the fish survive and its habitat [10]. However it can be overcome by increasing hatchery of any type fish endangered [11].

As for Malaysia, the potential energy from the ocean are thermal energy, tidal energy and wave energy. The ocean thermal energy required 20°C in the difference between warm sea surface and cold water seabed. The 1000 meters of depth are required to produce the temperature difference. However, Malaysia ocean is only around 50 to 200meters.

East of Sabah ocean however has the required depth but it is 200 to 300 km from its shoreline. The high cost of development needs to be invested to harvest this energy. For the wave energy, Malaysia ocean has only 0.5 to 1.5 meters height. The energy that can be produced is only 15kW per meter. This is too small to meet such high demand. The tidal current however require a minimum speed of 2.5 m s speed. Most Malaysia oceans averagely have 0.77m/s of current speed. The max speed of currents is around 1m/s to 1.2m/s. With a highly research turbine, this potential tidal current energy can be harvested to become the source of energy for Malaysia [12].

2.2 TIDAL FORMATION AND HISTORY

2.1.2 Tidal energy background

The formation of tidal happens when the earth rotates within the moon and sun gravitational fields [13]. Tides usually has three basic patterns, a half day (semi diurnal), daily (diurnal) and a 14-day cycle. A diurnal is cause by the rotation of earth position within the moon gravitational field resulting a 12 hour 25 minutes high level waters. Moreover, the diurnal tides have only one high and low tide within 24 hours. The 14 day cycle is caused by the superposition between moon and sun gravitational field. This formation is shown in figure 1.1**.**

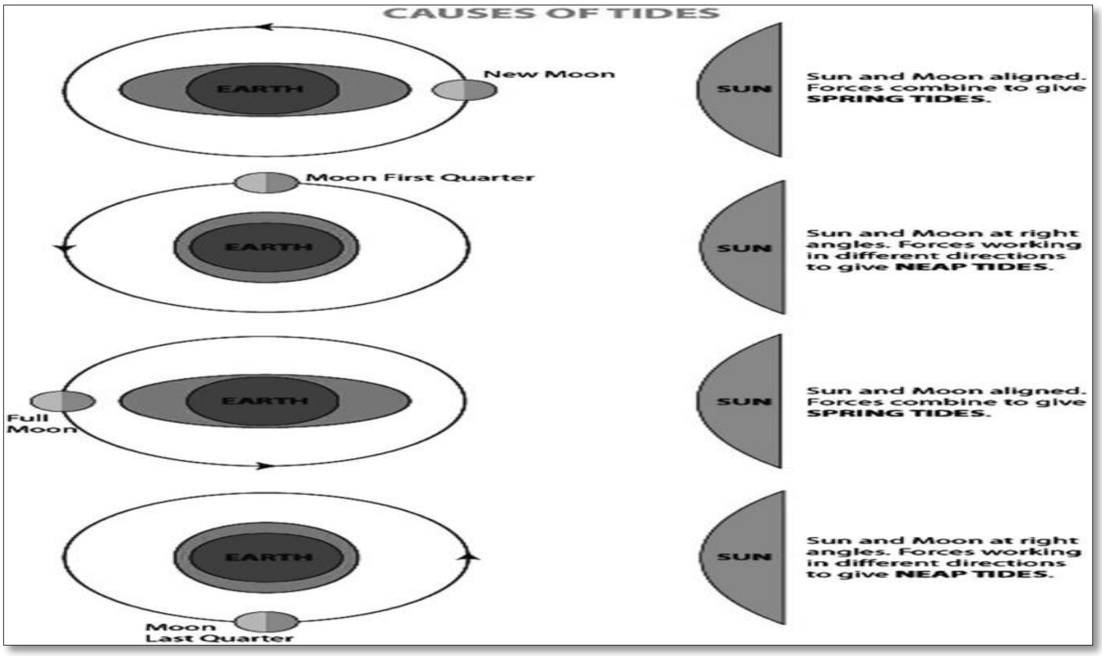

Figure 2.1: Formation of tidal.

Source: X. Sun (2008)

As the tidal formation can be predicted, this renewable energy can be very reliable compared to wind, thermal or wave energy. Hence, the tidal current energy can develop to its full potential [14]. The tidal current application has been used since a long time ago. The earliest date estimated is on 6th century located at Kiloteran near Waterford. It is the first vertical wheel tide mill.

Basically, two types of method use generate electricity from tidal movement [15]. The first method is by building a tidal barrage across an estuary or bay in high tides. This method manipulates the difference between high and low tides. However this method has a very high investment and also environmental issues [16]. Figure 1.2 shows the mechanical work of tidal barrage.

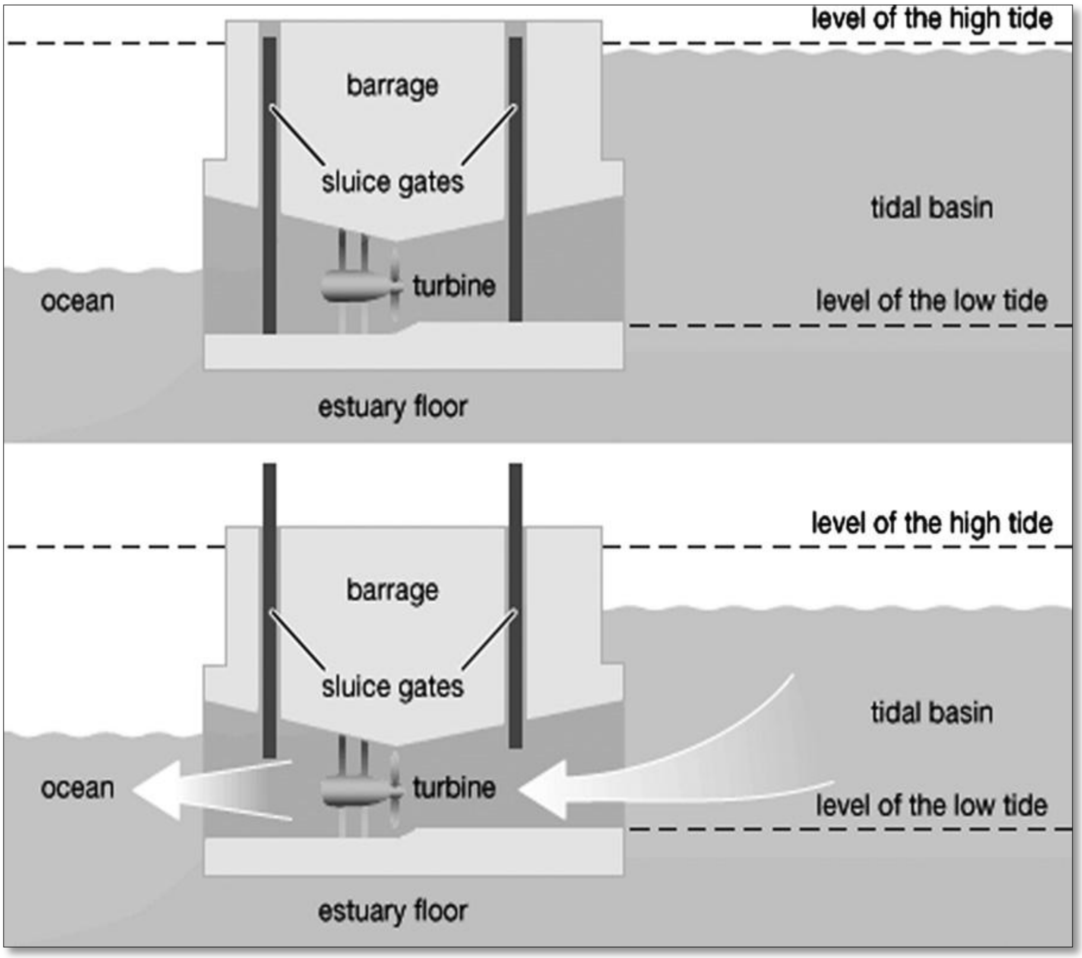

Figure 1.2: Tidal barrage fundamental.

Source: X. Sun (2008)

The most famous tidal barrage is on La Rance, France. It was open on 26th November 1966 and becoming the second largest tidal power station in the world. Currently generated by 24 turbines and can supply up to 240 Megawatts at its peak rate. In addition, it supplies 0.012% of France power demand [17]. It is located on the Severn Estuary between Cardiff and Bristol.

Figure 2.2: La Rance Tidal Power Station

Source: X.Sun (2008)

Figure 2.3: Location of LA Rance Tidal Power Station.

The second method is to build a tidal farm energy extractor. The kinetic energy of flowing water is transferred to electrical energy by energy converter [13]. The converter usually uses to capture the current is tidal current turbine. It applies the same concept as the wind turbine where the kinetic energy converts to electrical energy [18]. This technology also has less impact to the environment also it is deployed under the sea hence reduce the land use [5].

As for Malaysia, tidal energy is a promising renewable energy resource available [19]. A study by Ref [20] identified that Pulau Jambangan, Kota Belud and Sibu are the location with promising for tidal energy extraction. The estimated amount of electricity that can be generated at those three locations is about 14.5 GWh/year [19].

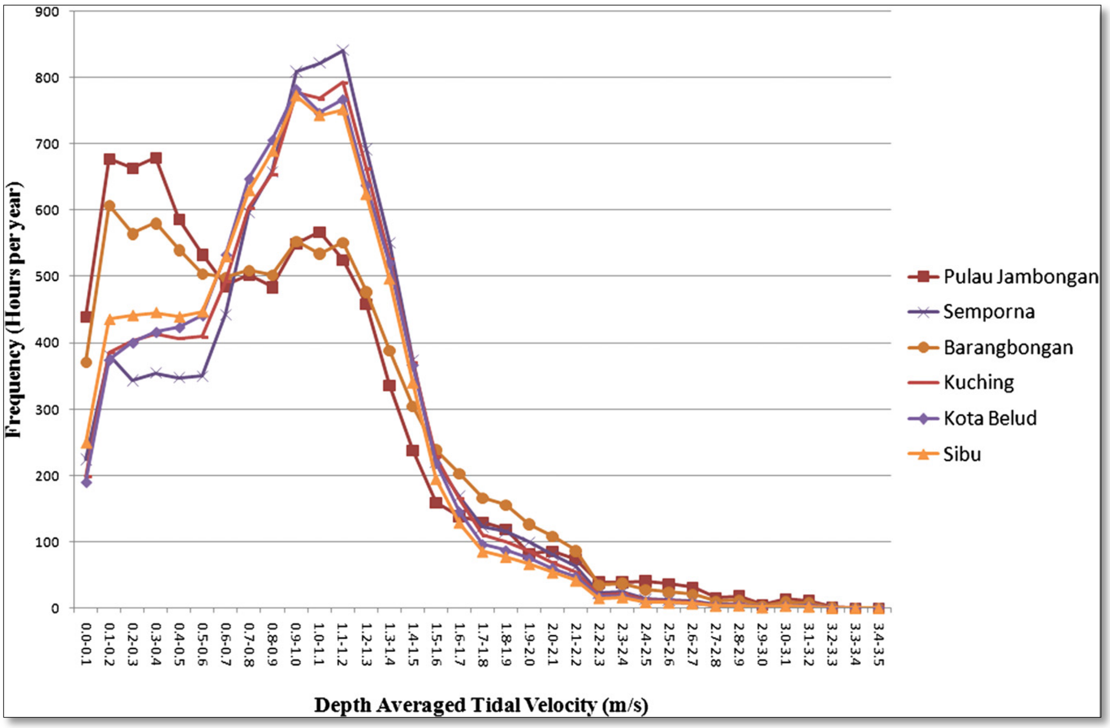

Figure 2.4: Distribution of tidal currents for Sabah and Sarawak.

Source: Y.S Lim (2009)

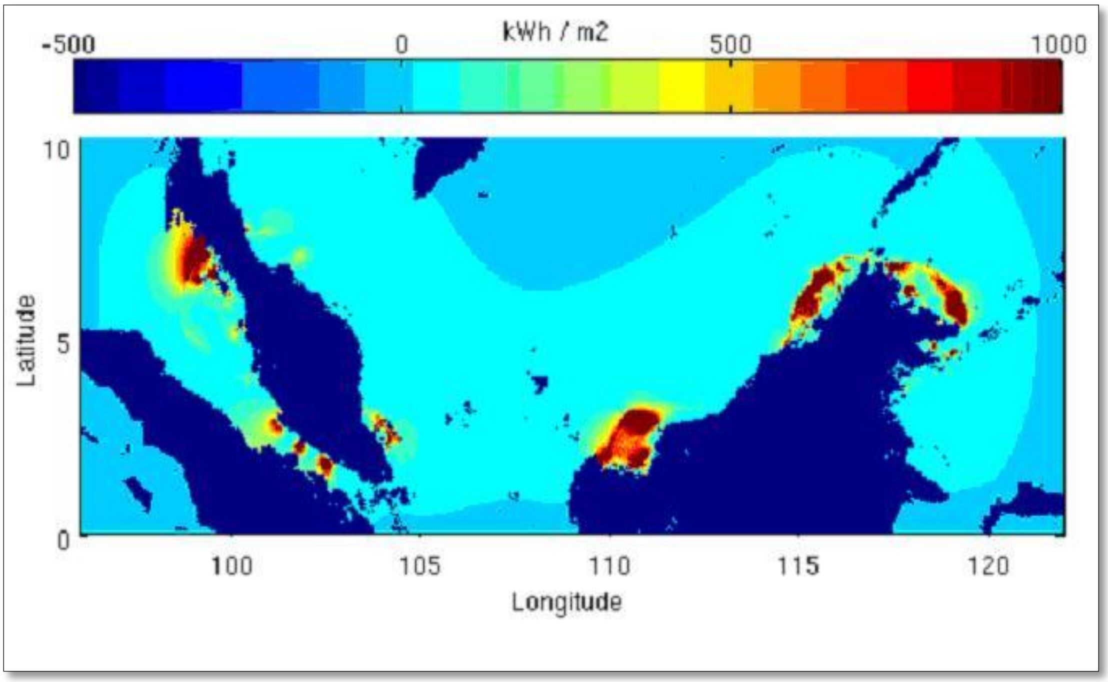

Figure 2.5: Energy density of tidal current in Malaysia.

Source: Y.S Lim (2009)

2.2.2 Tidal energy requirement

The tidal energy available is massive but still in most areas there is too low current speed which is not exceeding 2m/s [13]. The table below shows the relative power density of marine currents with wind and solar resource.

Table 2.1: Relative power density of marine currents with wind and solar resource**.**

Energy resource	**Tidal Currents**					**Wind**	**Solar**
Velocity (m/s)	1	1.5	2	2.5	3	13	Peak at noon
Velocity (Knots)	1.9	2.9	3.9	4.9	5.8	25.3	Peak at noon
Power density (kWm)	0.52	1.74	4.12	8.05	13.91	1.37	~1.0
Note: 13 m/s is a typical velocity at which maximum power is achieved for a wind turbine							

Source: X. Sun (2008)

Other criteria which need to be considered for the requirement to install the turbine is water depth. At 15 m depth at low tide minimum is ideal for 10 m rotor in diameter, at high tide, the height is 50 m at maximum [13]. The table below shows the suggested criteria for horizontal axis tidal current turbine rotor diameter.

Table 2.2: Influence of water depth on maximum permitted turbine.

Water depth	**Rotor diameter (assuming no shipping conclusion)**	**Rotor diameter (assuming shipping exclusion)**
<20m		10m
20-25m	5m	120m
25-40m	10m	20m
>40m	20m	20m

Source: X. Sun (2008)

Malaysia, the country which has large areas of sea, has places where marine current turbines can be installed. According to Y.S Lim [1], three places which has the potential extractable energy is Pulau Jambongan, Kota belud, and Sibu. Below are the table develop using the Princeton Ocean Model (POM) by him.

Table 2.3: Locations and the corresponding potential energy output of an MCEC array, assuming that the power coefficient Cp = 0.4 and the minimum operating current speed is 1.1 m/s.

Locations	**Extractable energy ($kWh/m^2/year$)**	**Nominal depth**	**Rotor dameter**	**Number of MCTs that can be installed on the site**	**Total swept area (km^2)**	**Energy output (GWh/year)**
Pulau Jabongan	50.16	33	18	50 x 50	0.6	30
Kota Belud	1153.27	93	60	50 x 50	7.1	8188
Sibu	644.60	53	30	30 x 30	0.6	386
Total (GWh/Year)						8604

Source : Y.S. Lim (2009)

In addition, if three of this location utilized this tidal energy, 10% of 83,300 GWh/year of electricity demand in Malaysia will be generated by marine current turbine (MCT) [1].

2.2.3 Types of tidal curent energy extractor

There are numerous number of marine current turbines develop from now. Basically there are two types of tidal current energy extractor. This is the most common use of turbine types.

1. Horizontal axis turbine
2. Vertical axis turbine
3. Variable foil systems
4. Venturi systems

The horizontal axis turbine extracts energy the same way as the wind turbine extract energy from moving air [15]. It works when the inflow perpendicular to the rotor causes a resultant hydrodynamic force, which has components acting normal to the axis of the rotor blade in the plane of rotation [13]. The resulting torque is transferred by a shaft and gearbox to an electrical generator [21].

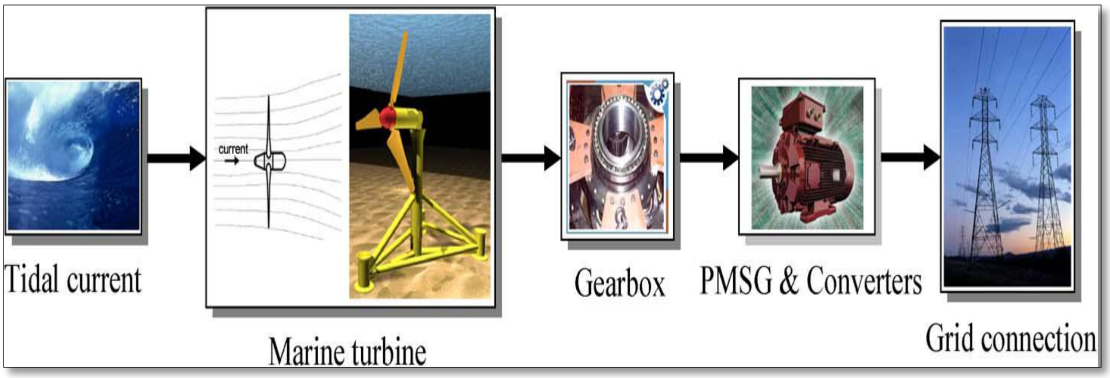

Figure 2.6: Marine current turbine global block diagram.

Source: Benelghali (2011)

The most successful example of a horizontal axis turbine is the Seaflow developed by Marine Current Turbine Ltd. In 2003, MCT in association with Seacore successfully installed the 300kW Seaflow in the Bristol Channel near Lynmouth, United Kingdom [22].

Figure 2.7: Marine Current Turbine Seaflow

Source: Benelghali (2011)

For the vertical axis turbine, the blades and rotor transmission shaft are parallel to one another and are both oriented perpendicular to the incoming current flow [13]. Two types of vertical axis turbine are Savonius type and Darrieus type. The Savonius type is a drag type and the Darrius type apply a lift type.

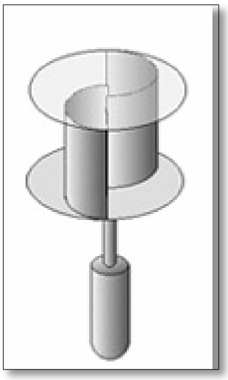

Figure 2.8: Savonius type.